Venus Aircraft
design evolution 2000- 2008

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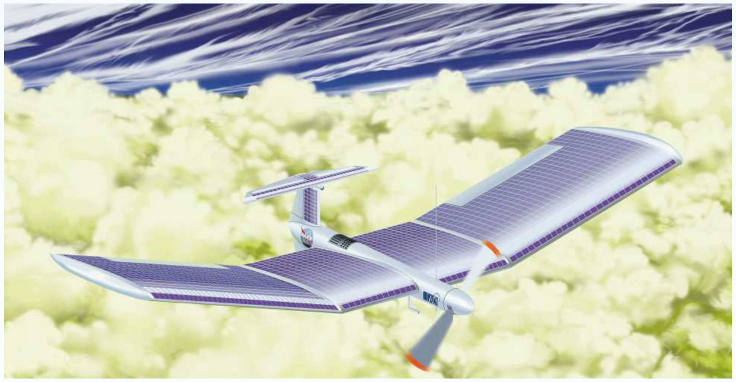
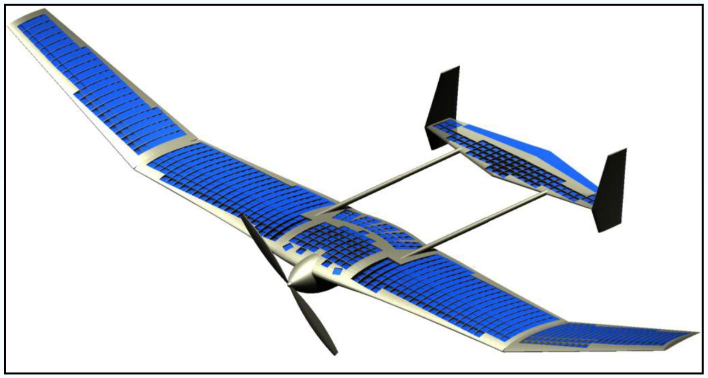
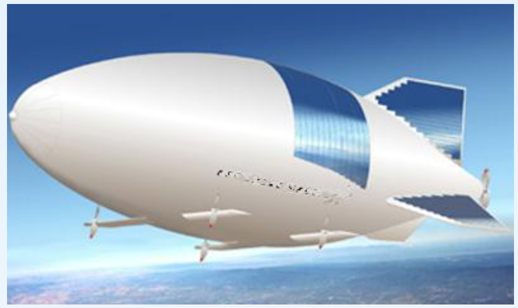
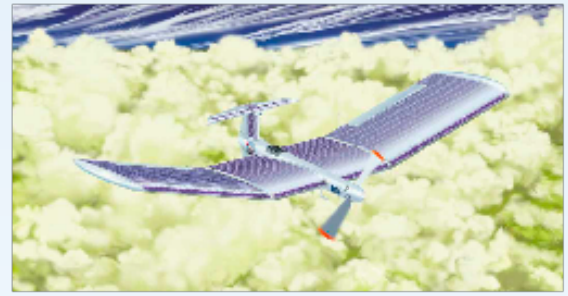




Atmospheric exploration trade-study





•Balloon

•Simple technology

•Demonstrated on Venus

•Altitude change possible, but difficult

•Location change not possible

•Airship

•Difficult to stow and deploy

•Altitude change possible, but difficult

•Speed is slow:

- •cannot stationkeep
- •cannot stay in sun
- •Can keep latitude (depending on altitude)

•Airplane

•Airplane design uses terrestrial experience

•Stow and deploy concepts demonstrated by ARES

•Altitude change easy (within design limits)

•Speed allows stationkeeping and continuous sun

•Easy to keep latitude

(simplified) Aerodynamics of flight on Venus

- Horizontal flight requirement: lift on wing = gravity

- $F = \frac{1}{2} \rho C_L A V^2 = mg$

  Variables
  - ρ (atmospheric density): function of altitude
  - C_L (lift coefficient): typically around 1 for optimum flight
  - A (wing area)
  - V (velocity)

Flight velocity and power:

- $V = \mathrm{SQRT}\ (mg/A)/(2\rho C_L)$
  - Note that (m/A) = wing loading
- Power = drag force times velocity
  - If we make the simplifying assumption that drag is proportional to lift via the L/D (lift to drag) ratio, and C_L is approximately 1:
- $P = mg/(L/D)*V = (mg)^{3/2}\ (L/D)\ (2\rho A)^{-\frac{1}{2}}$

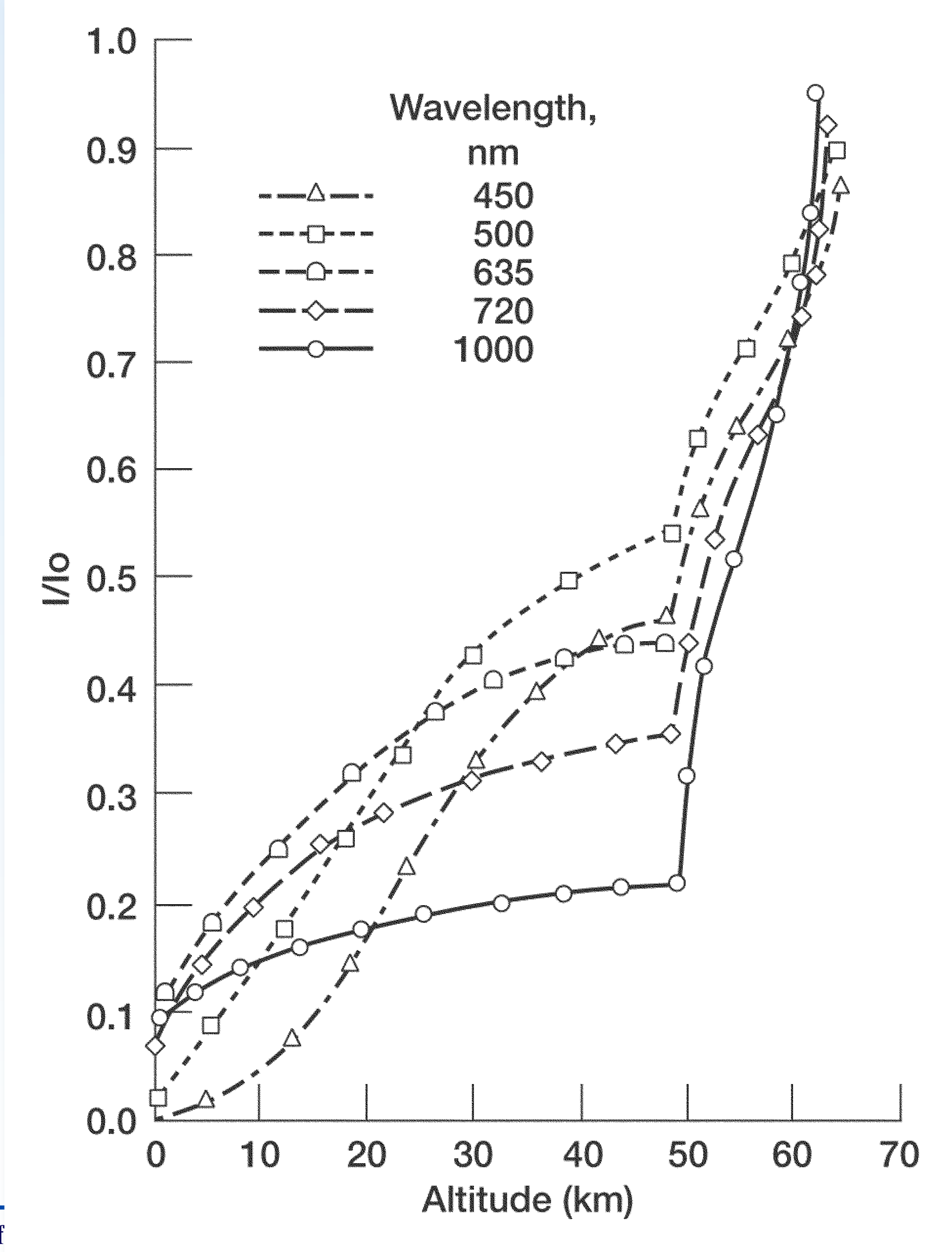
Solar Airplane Figure of Merit

- We can calculate a *solar airplane figure of merit* showing the ratio of sun intensity to the power required for level flight at a given wing area. The solar intensity is proportional to $1/d^2$, and power required to fly proportional to the square root of the atmospheric density. Thus: flying is easiest on a planet close to the sun with high atmospheric density:

If we simplify by neglecting the parasitic drag (proportional to v^3) the figure of merit F is

Planet	d (AU)	g (gravities)	ρ (bar)	F
Earth	1	1	1	1
Venus	0.723	0.91	1	2.2
Mars	1.524	0.38	0.0064 (average)	0.15
Jupiter	5.203	2.36 (equat.)	1	0.01
Saturn	9.572	0.92 (equat.)	1	0.01
Titan	9.572	0.14	1.5 (at surface)	0.27

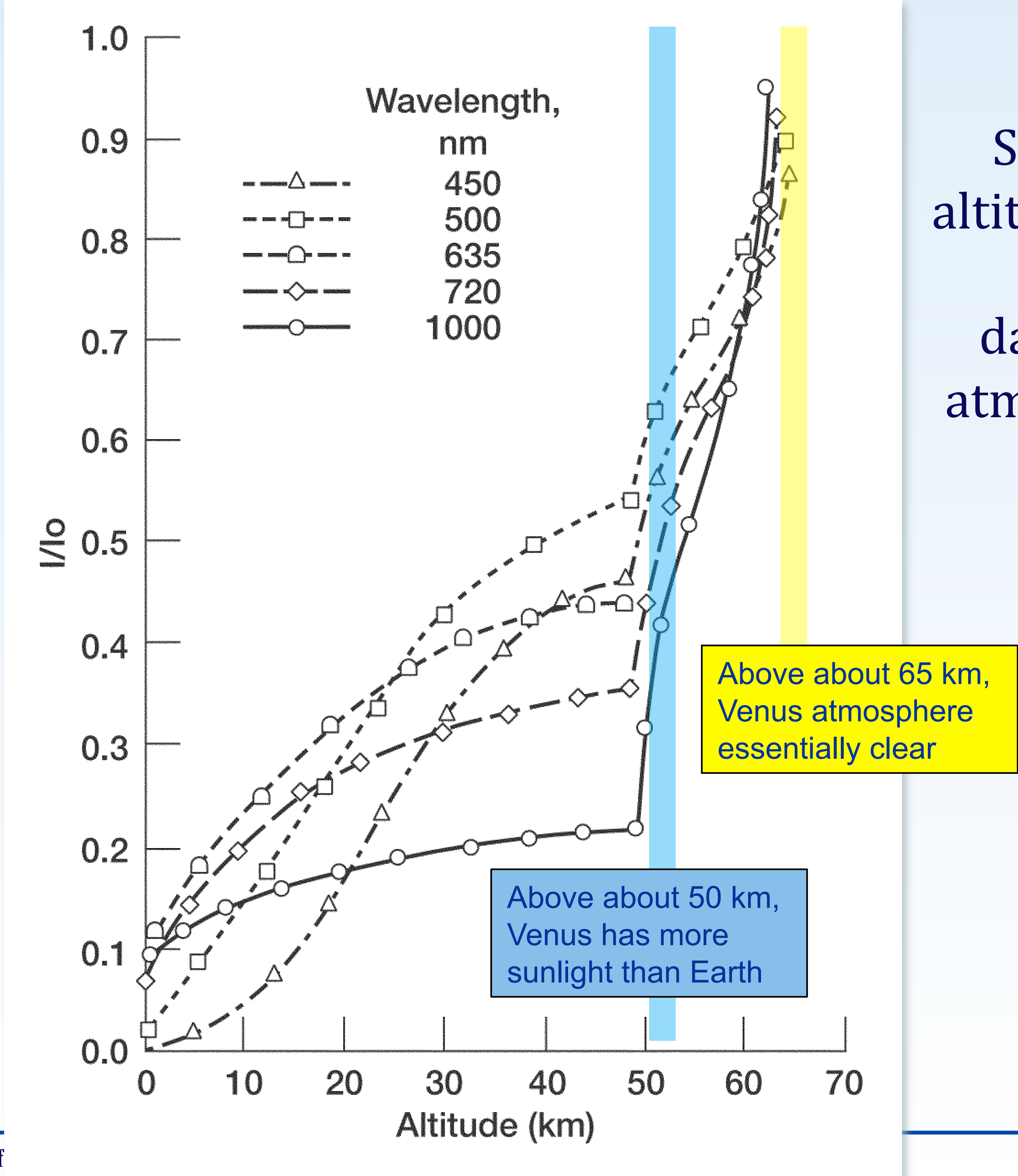
For Venus, Jupiter, and Saturn, flight is assumed to be at the one bar level
Does not include effect of atmospheric opacity



Solar energy vs altitude in the Venus atmosphere: data from Venus atmospheric probes

- At surface, power available is 10% of exoatmospheric power at 1000 nm, <1% at 450 nm

Solar energy vs altitude in the Venus atmosphere: data from Venus atmospheric probes



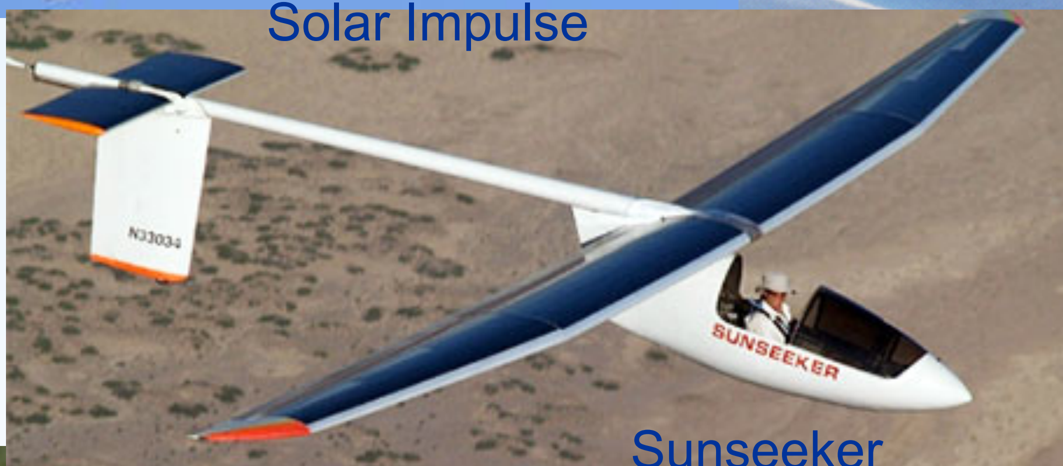
Solar Airplane Figure of Merit

- •50-60 km above surface, Venus atmosphere density profile similar to Earth's
  - •Airplane design can use Earth experience
- •Gravity 90% of Earth's
  - •Powered flight easier
- •Above the clouds, Venus has more sunlight than Earth
  - •Solar flight is easier on Venus than on Earth
- •Acid droplets in atmosphere require all exposed surfaces be corrosion resistant
  - •Avoid exposed metal surfaces.
  - •All metal surfaces need passivation coating
  - •Acid-resistant materials are well developed technology

Solar airplanes on Earth

Solar Impulse

Aerovironment “Pathfinder”



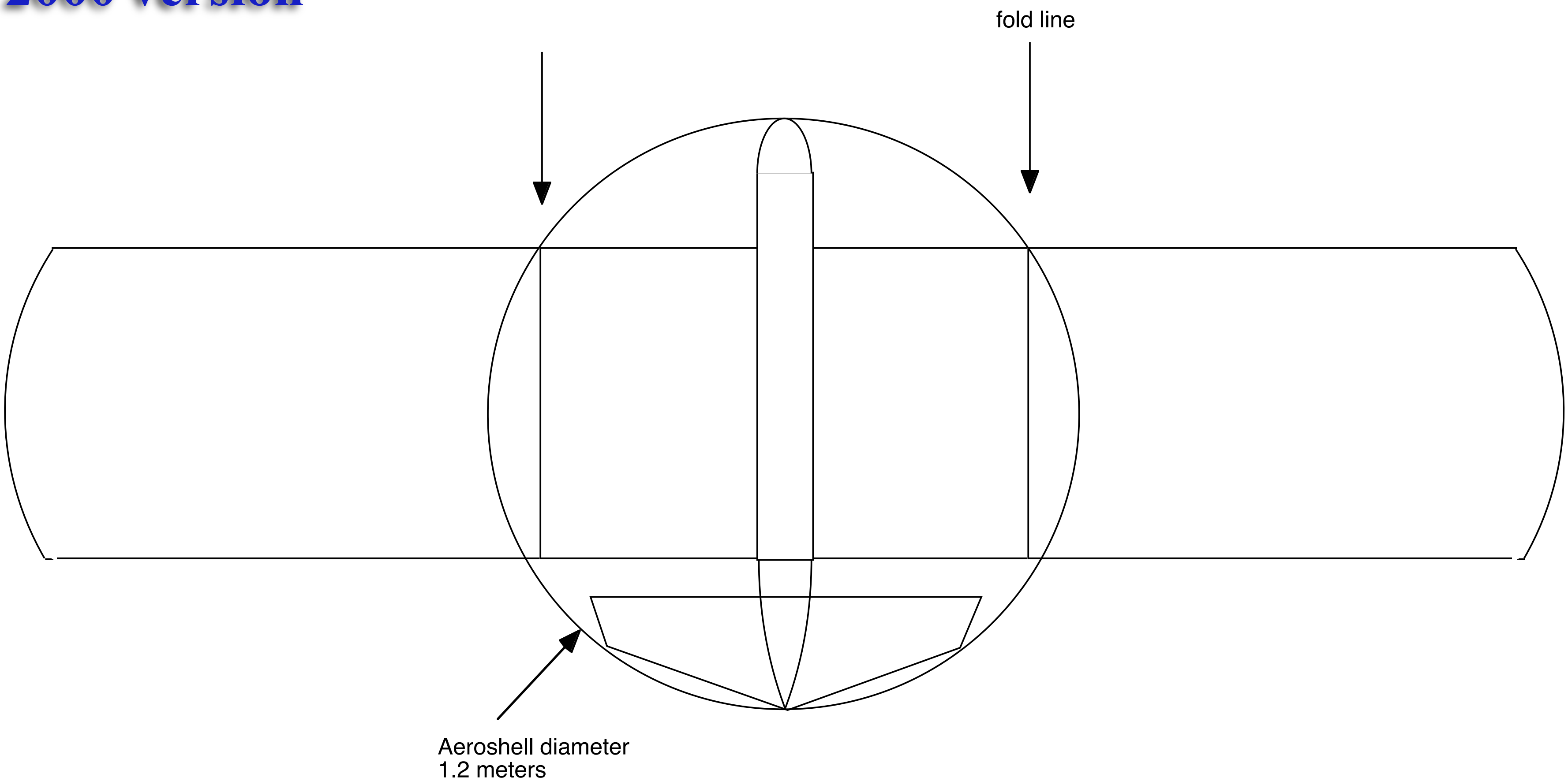
Sunseeker

NASA Glenn solar airplane team

Sky Sailor

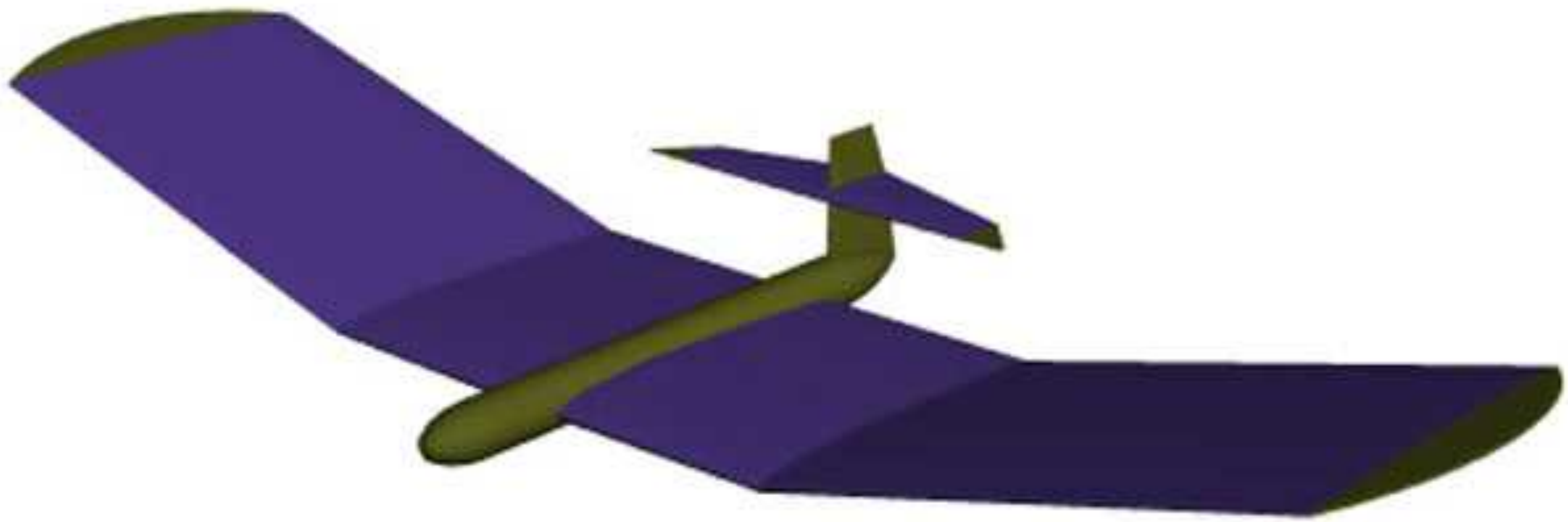
Initial sketch of wing-folding for small aircraft for Venus

2000 version



Aircraft concept was essentially a flying-wing design. A small tail gives a small amount of additional control authority with no additional fold.

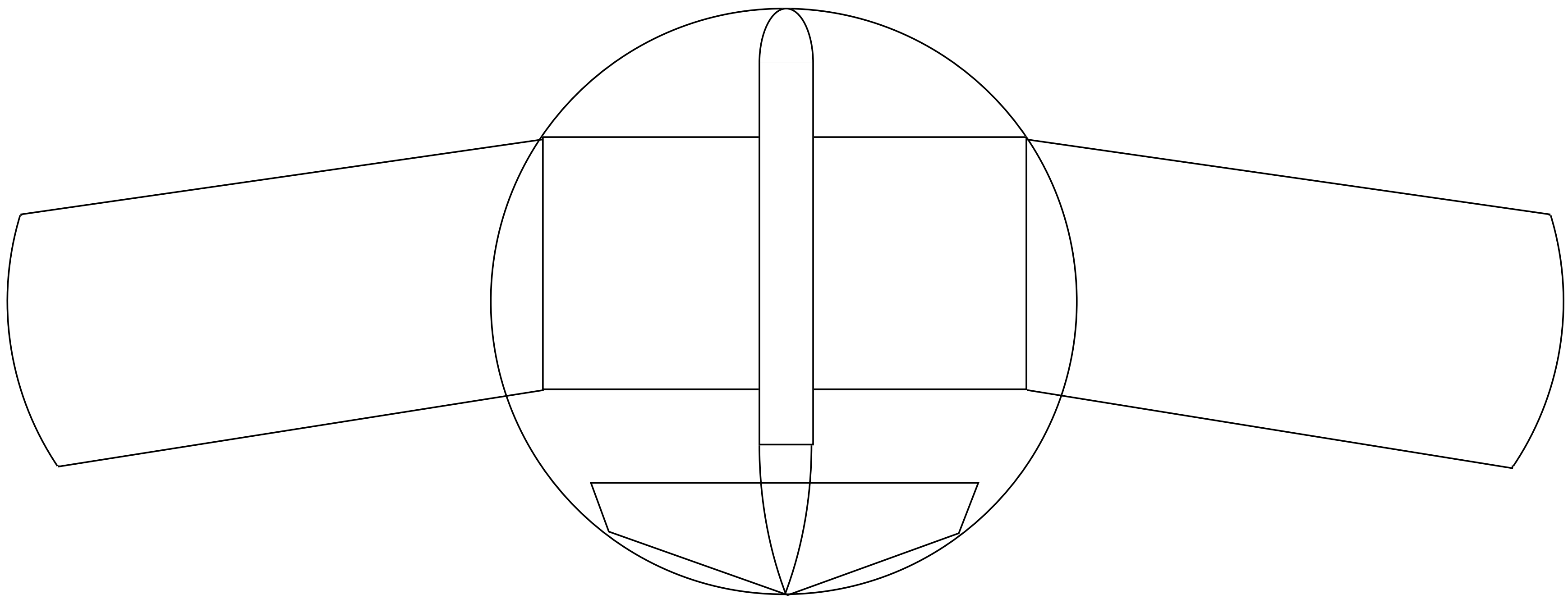
Early Venus aircraft design: 3-D modelled



Venus airplane initial concept

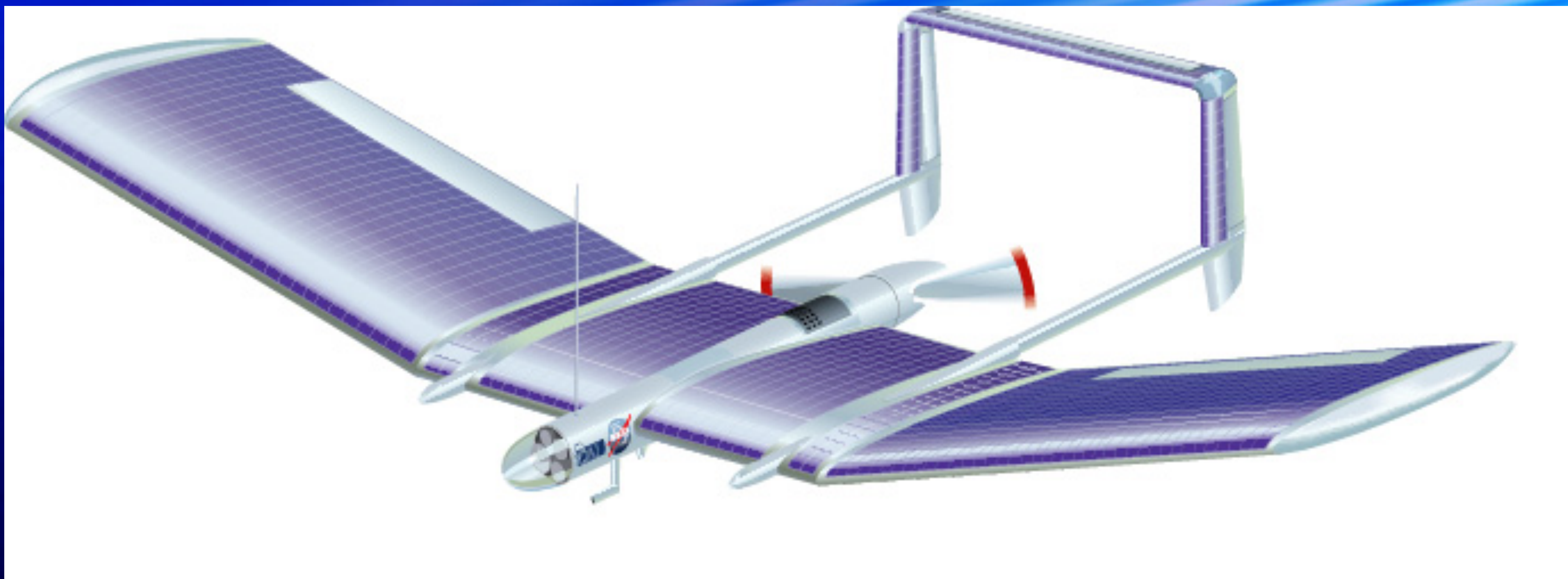
artist's conception by Les Bossinas

Variant 2000 small Venus aircraft



Venus airplane
3 folds
Medium wing chord version

Small Venus aircraft: OAI 2001 proposal



Chris LaMarre's Venus Airplane configuration August 2001

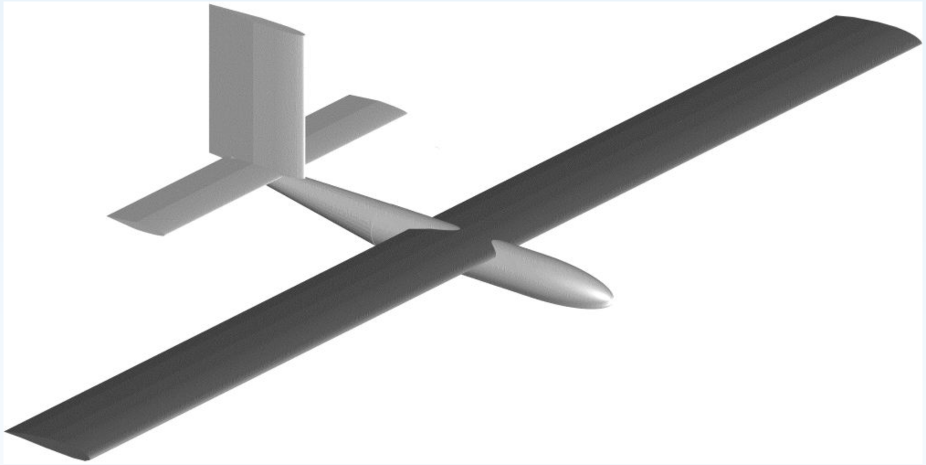
$S = 1.6\ m^2$

$b = 4.38\ m$

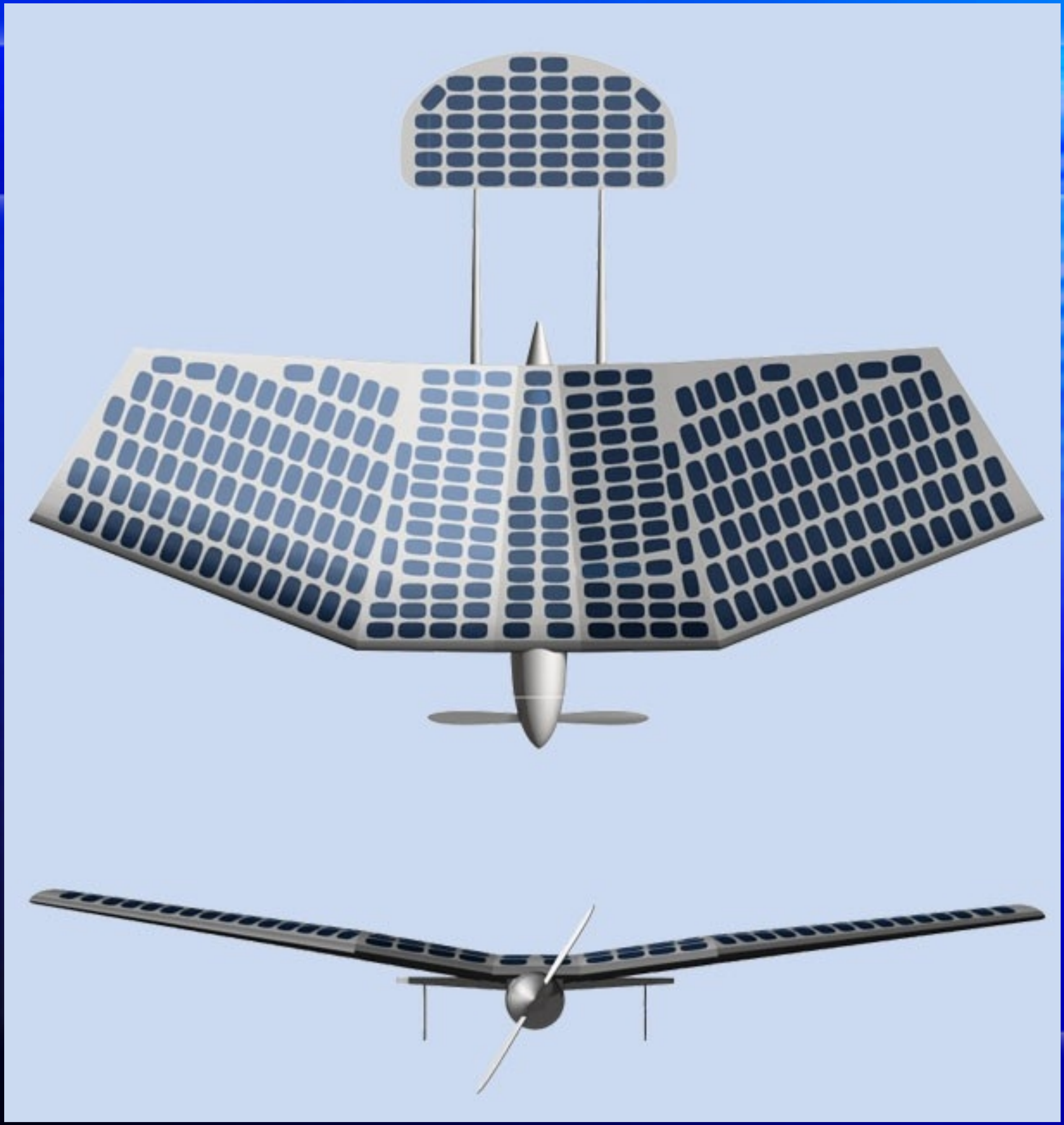
$AR = 12$

Mass = 15 kg

DF 101 and SG8000 airfoils investigated

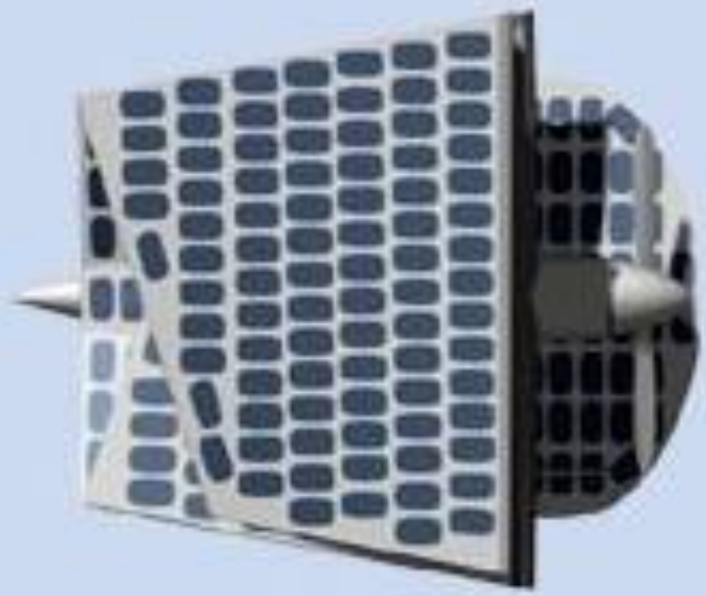


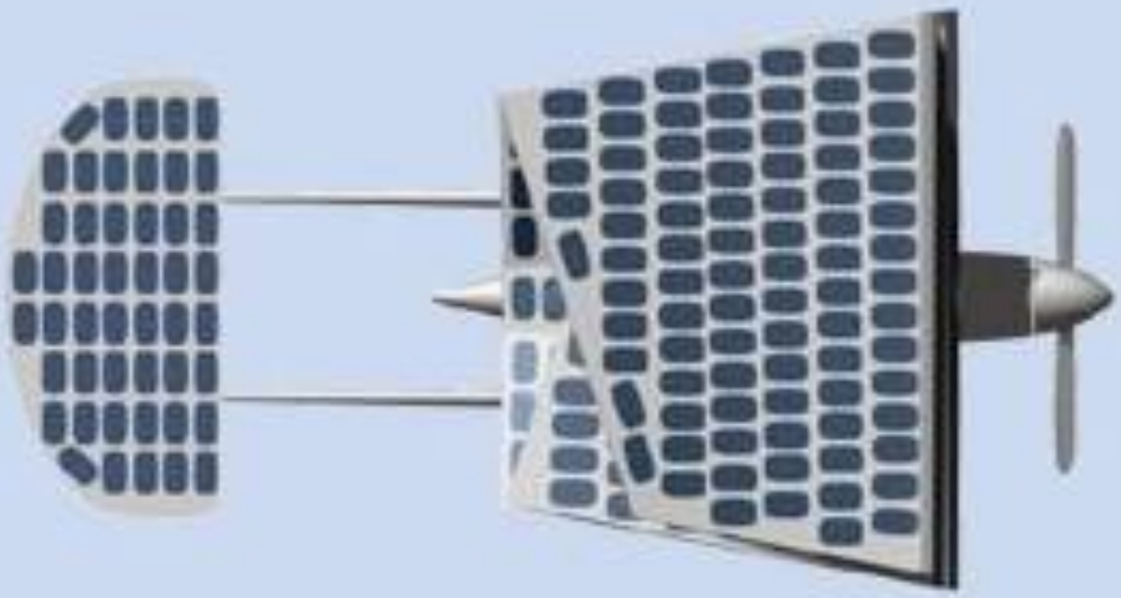
Design concept 2002



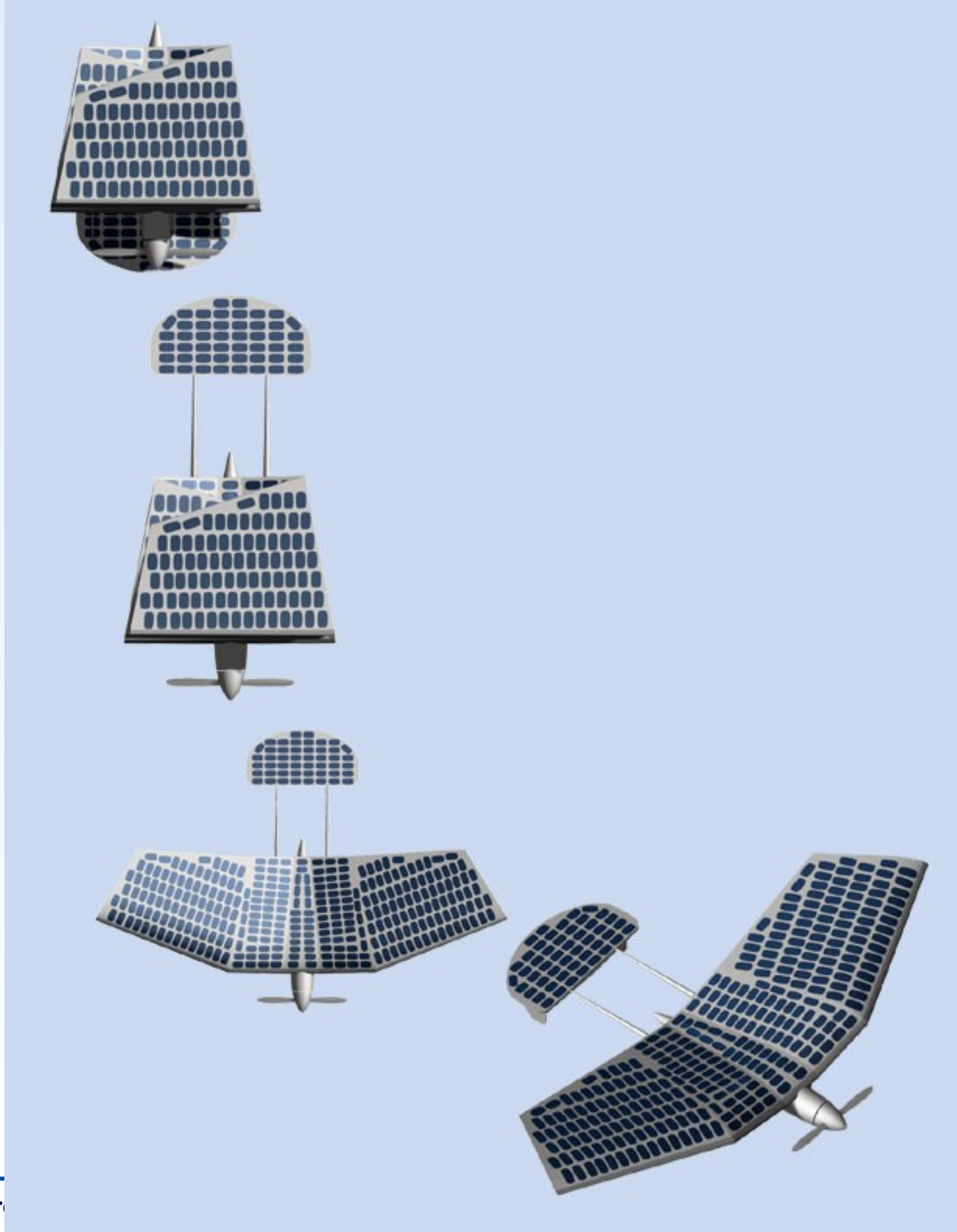
2002 folding concept

Folded in aeroshell

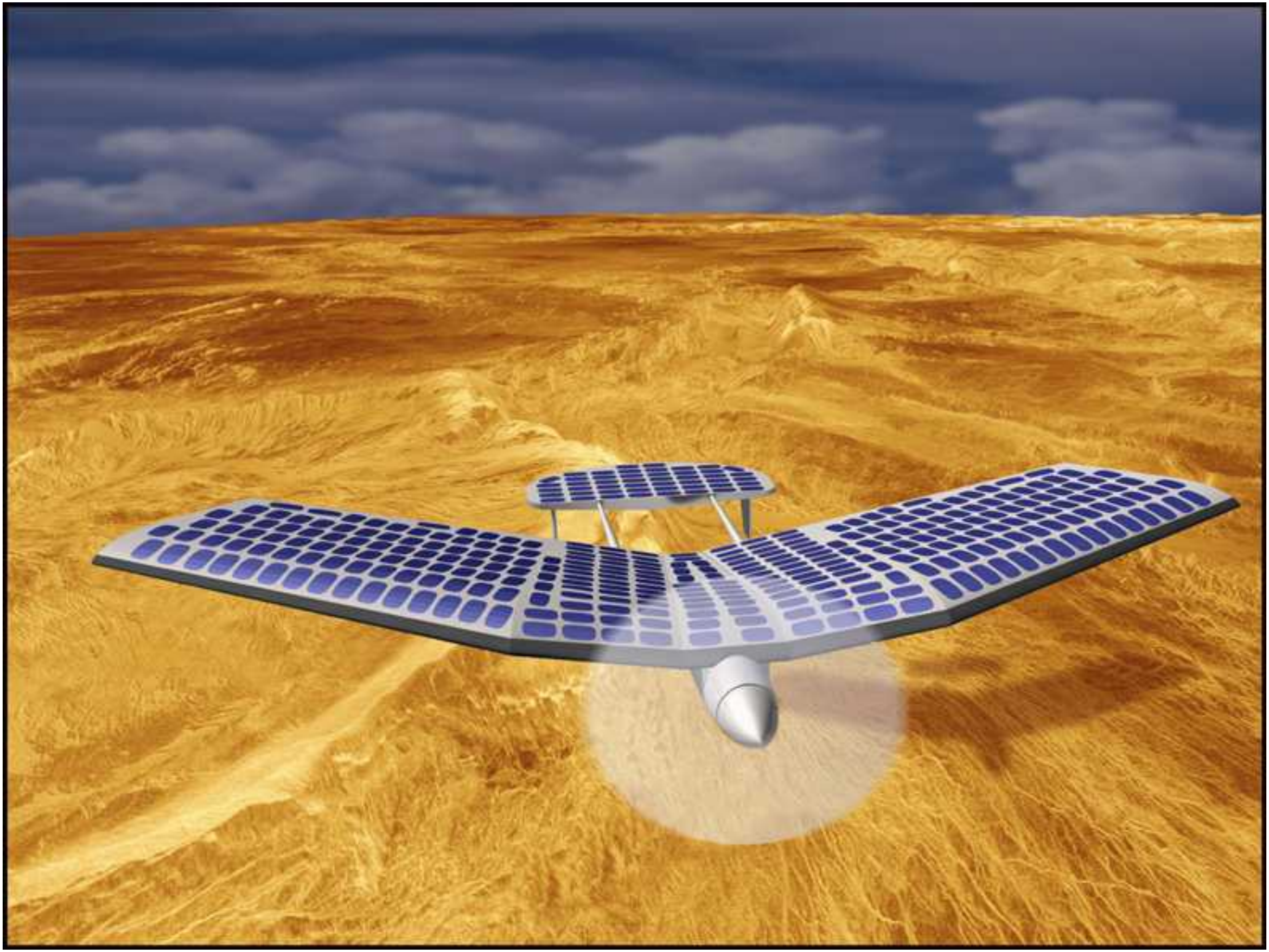




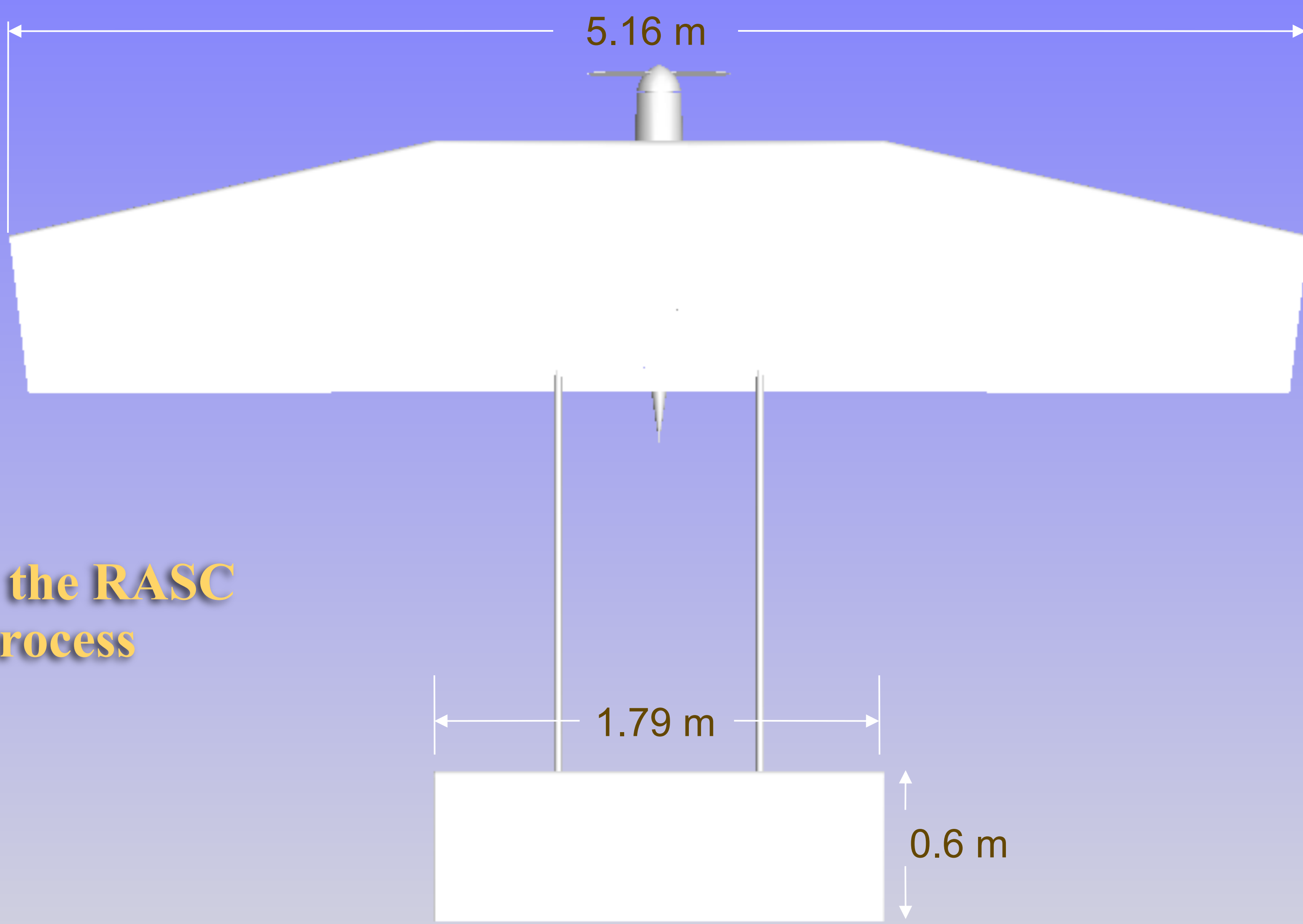
tail deployed

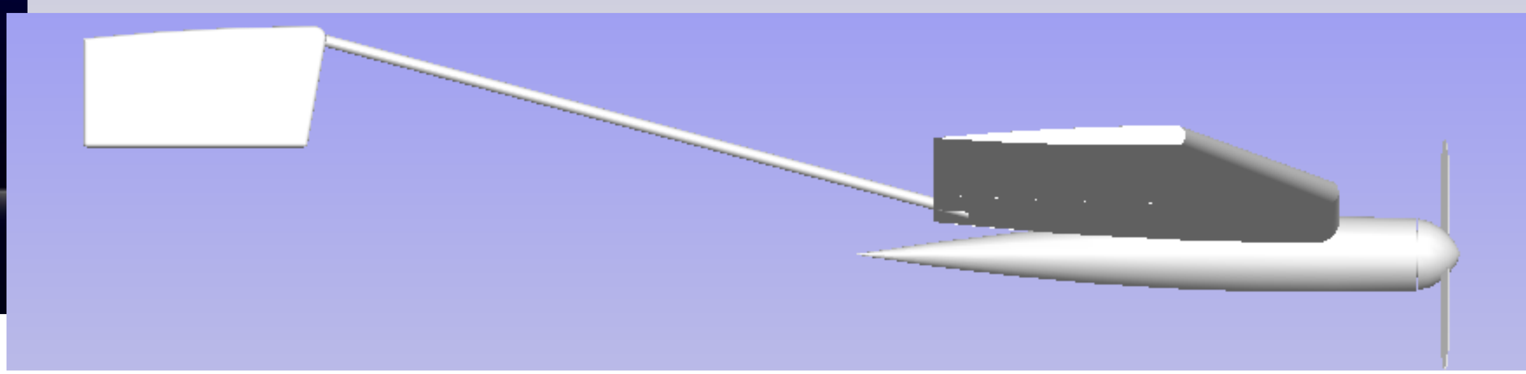


Venus airplane unfolding

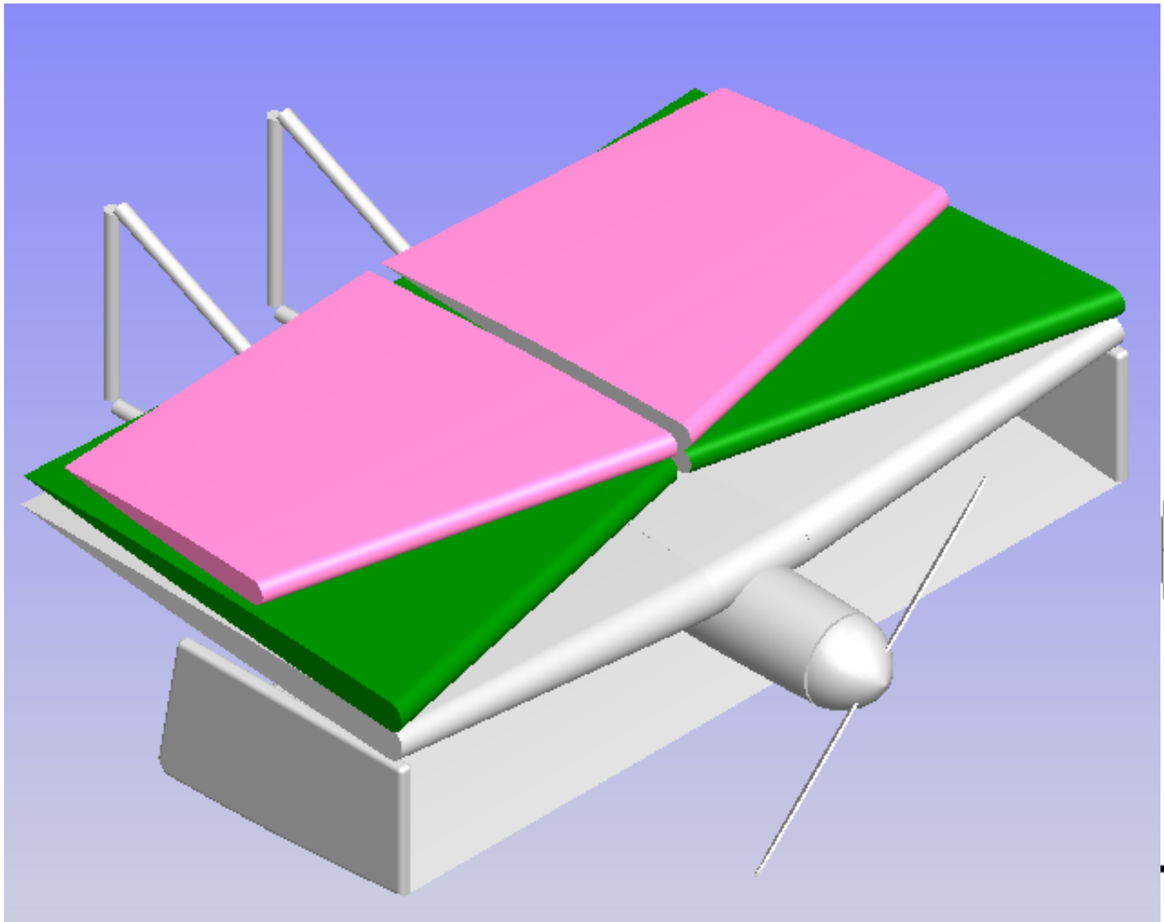


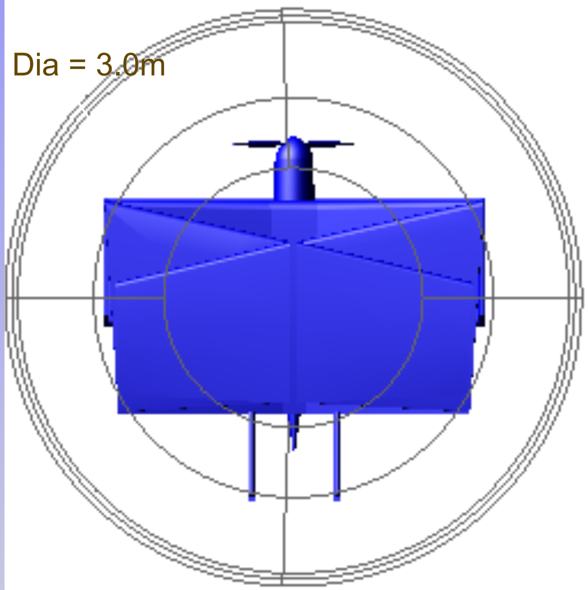
Early in the RASC design process



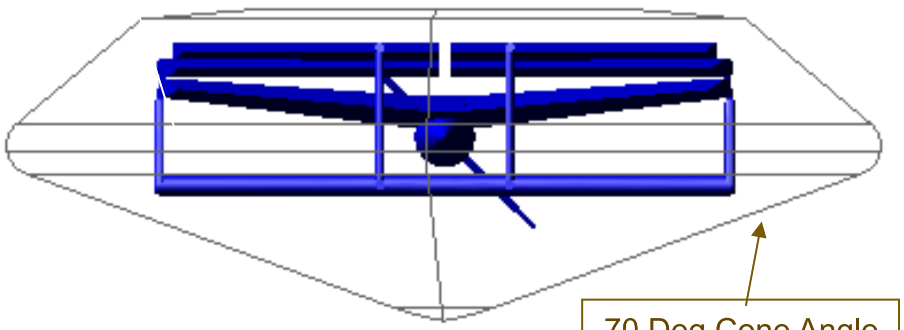


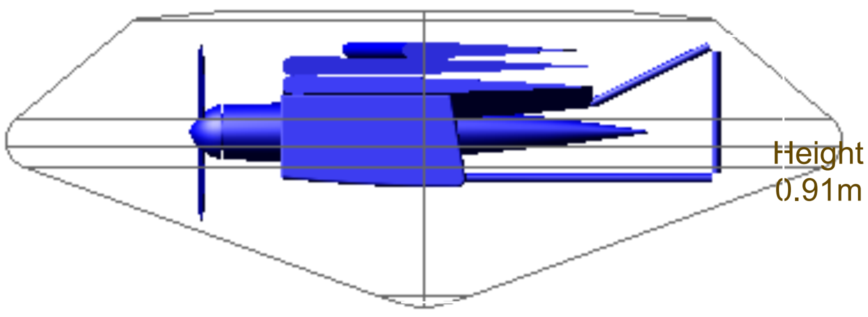
Folding for initial RASC version



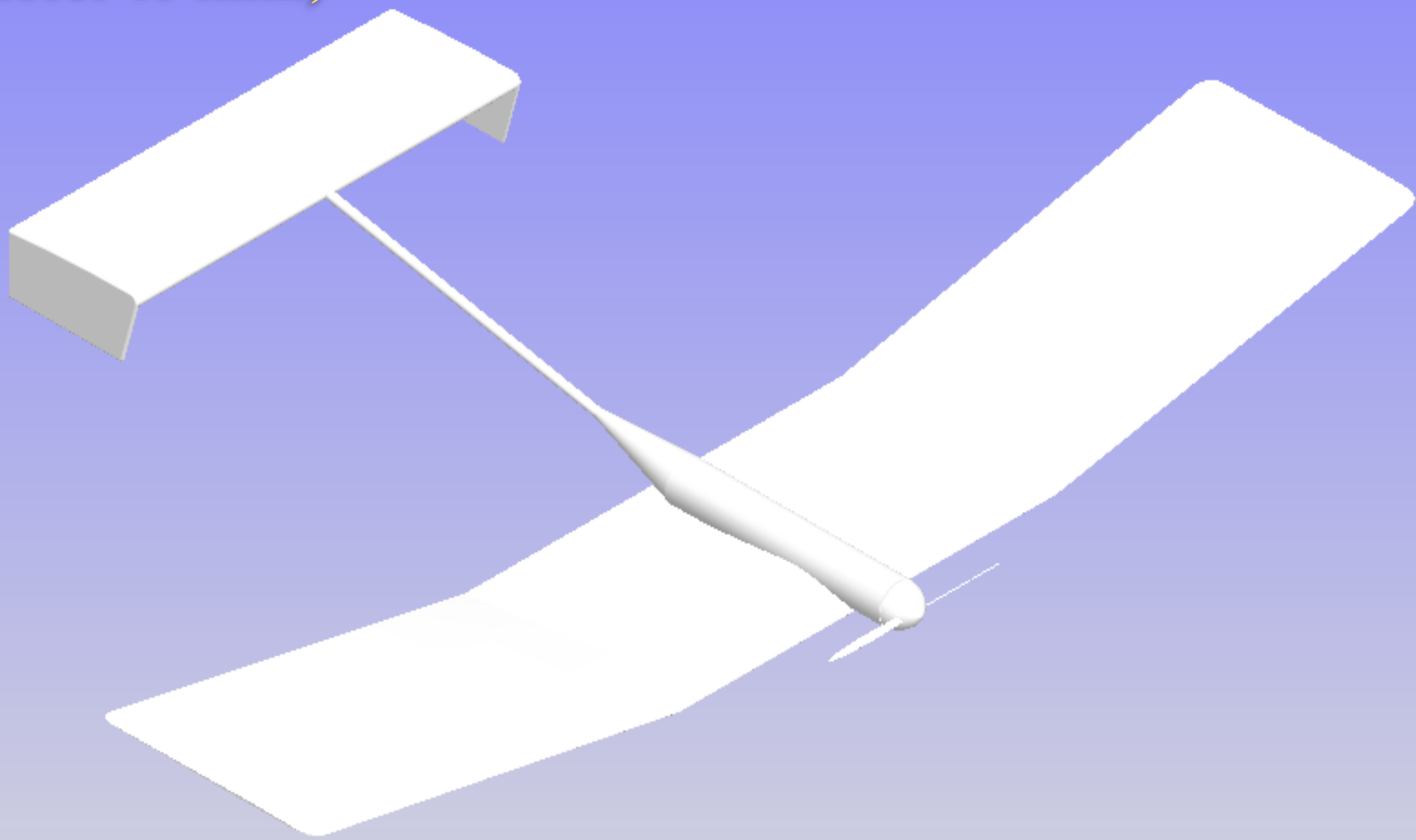


3.0m Aeroshell

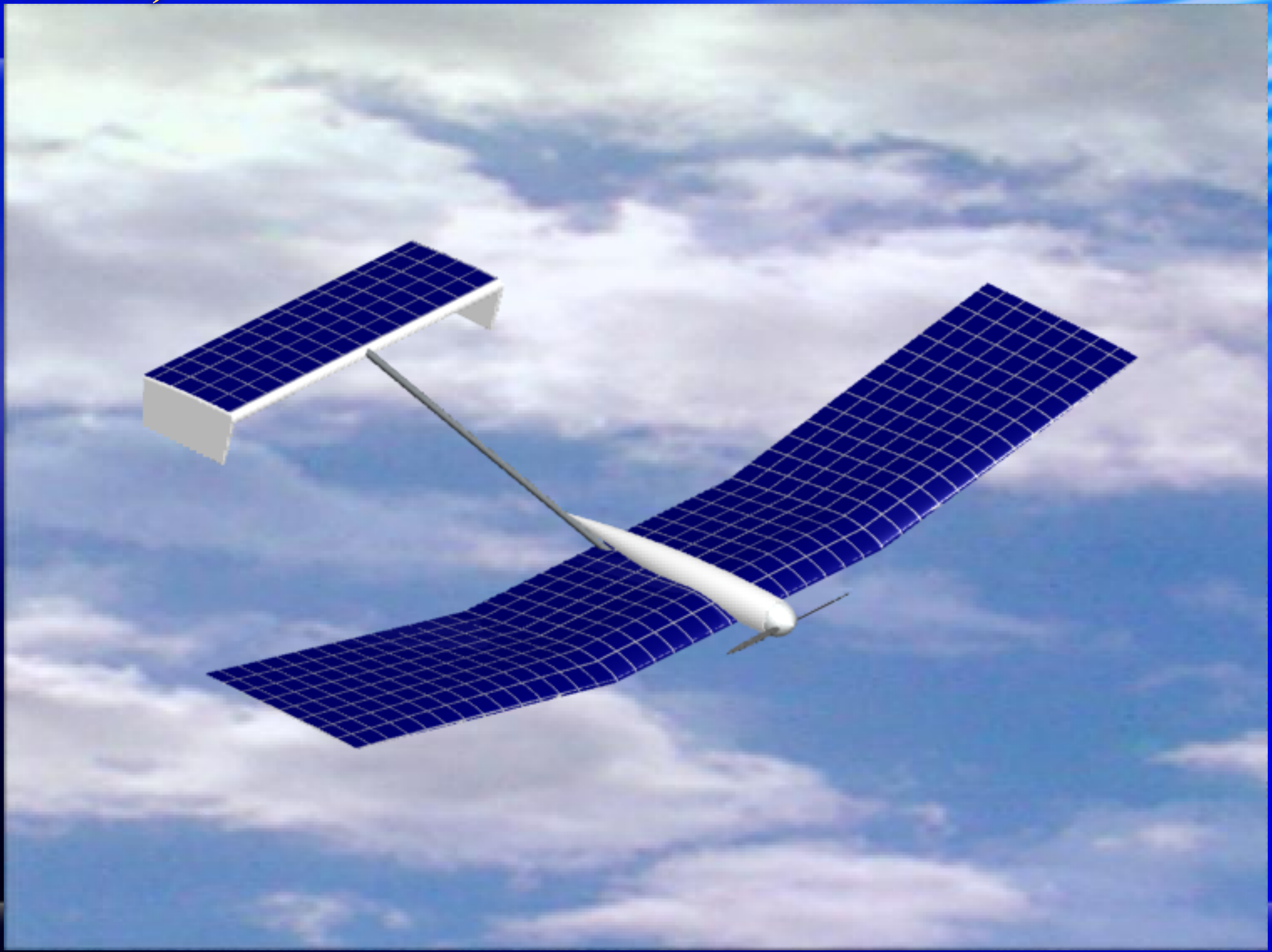




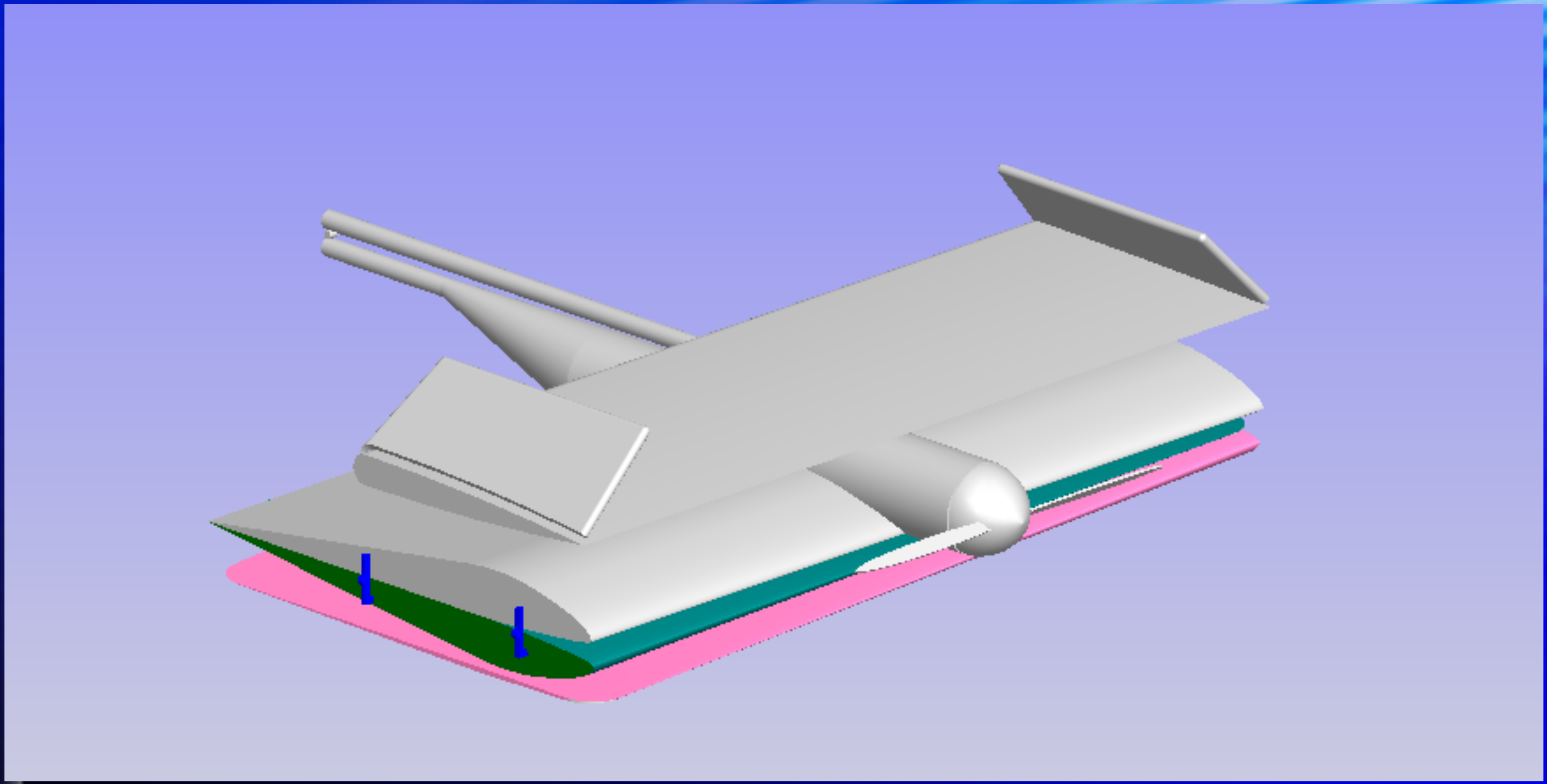
RASC- August 2003
(closer to final)



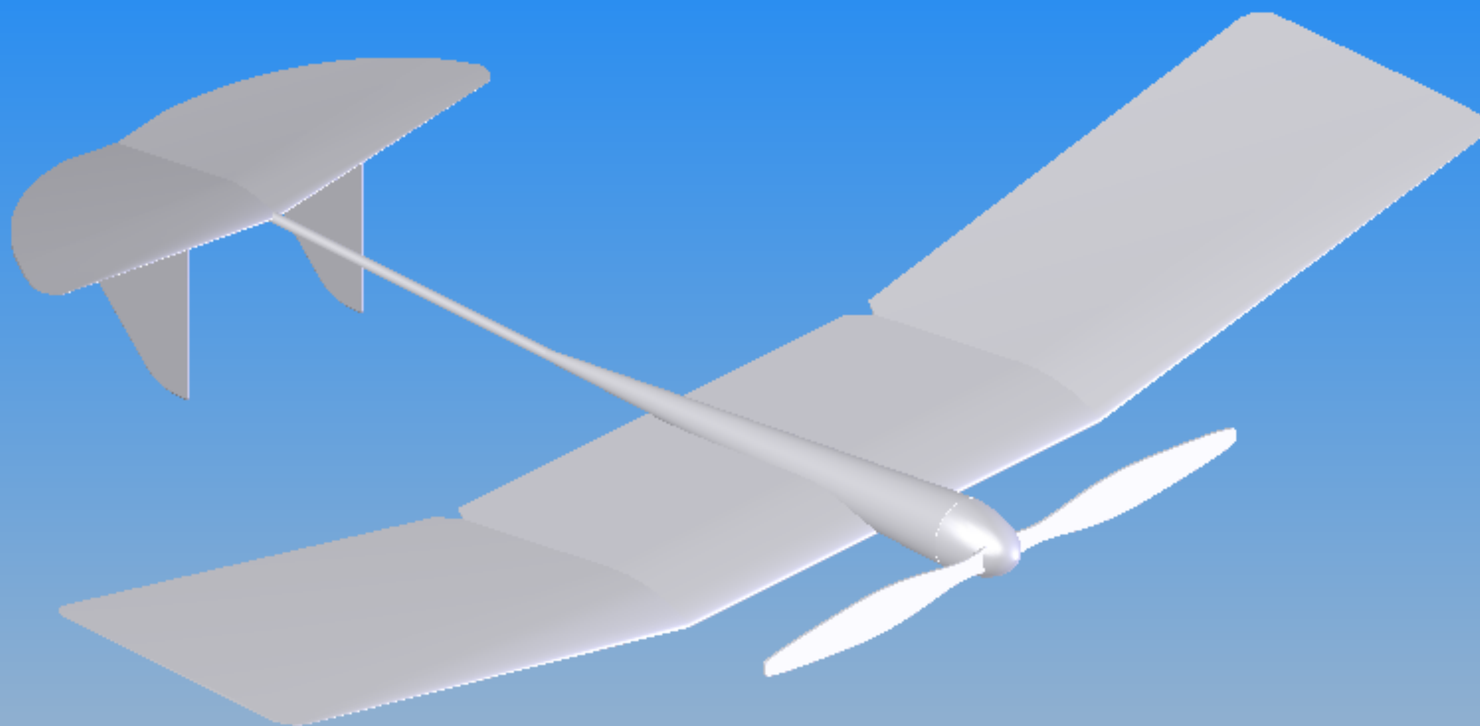
RASC- August 2003
(rendered)



RASC- August 2003
(folding scheme still needs work!)

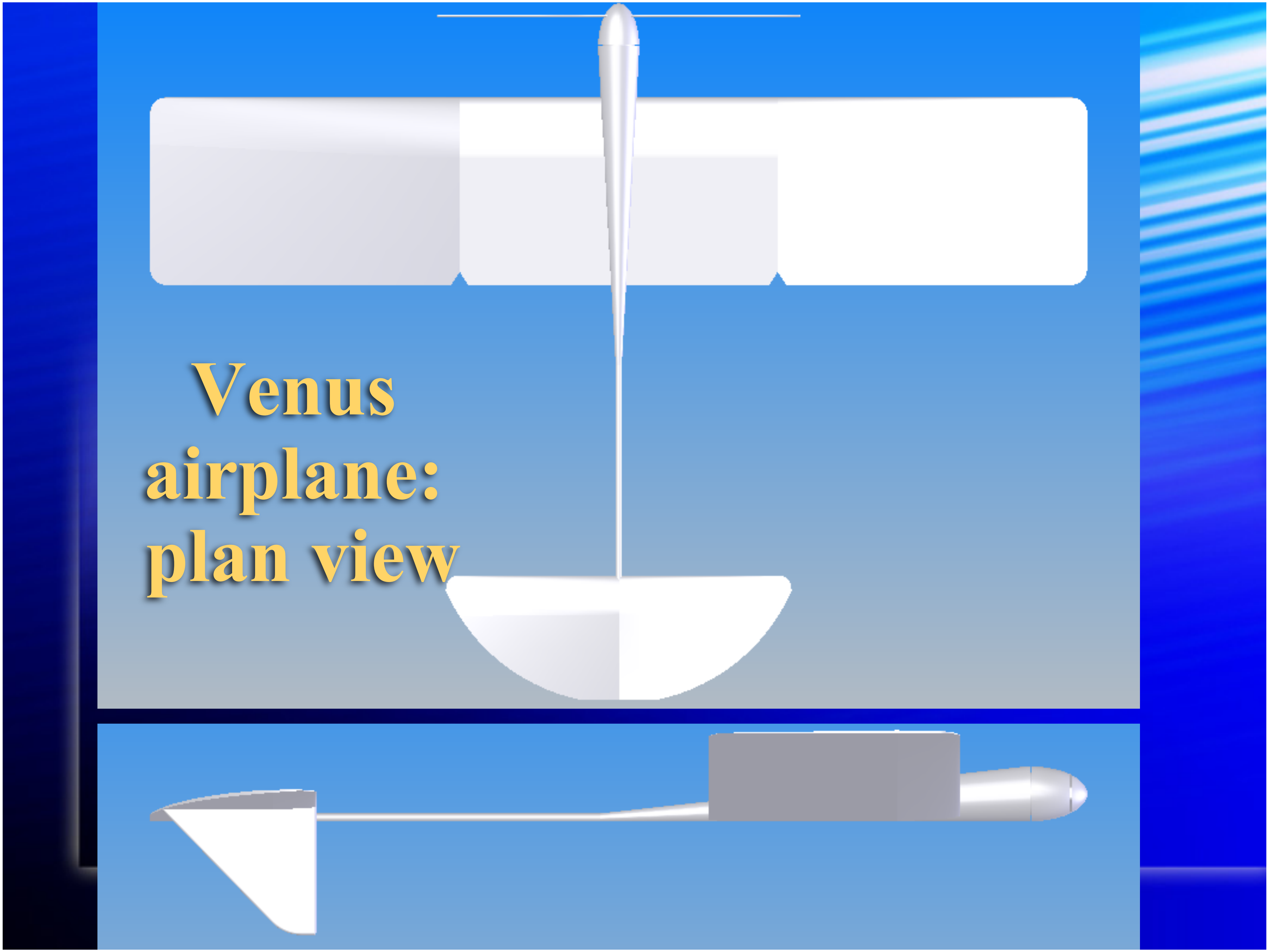


RASC Venus airplane: final design



See animation at

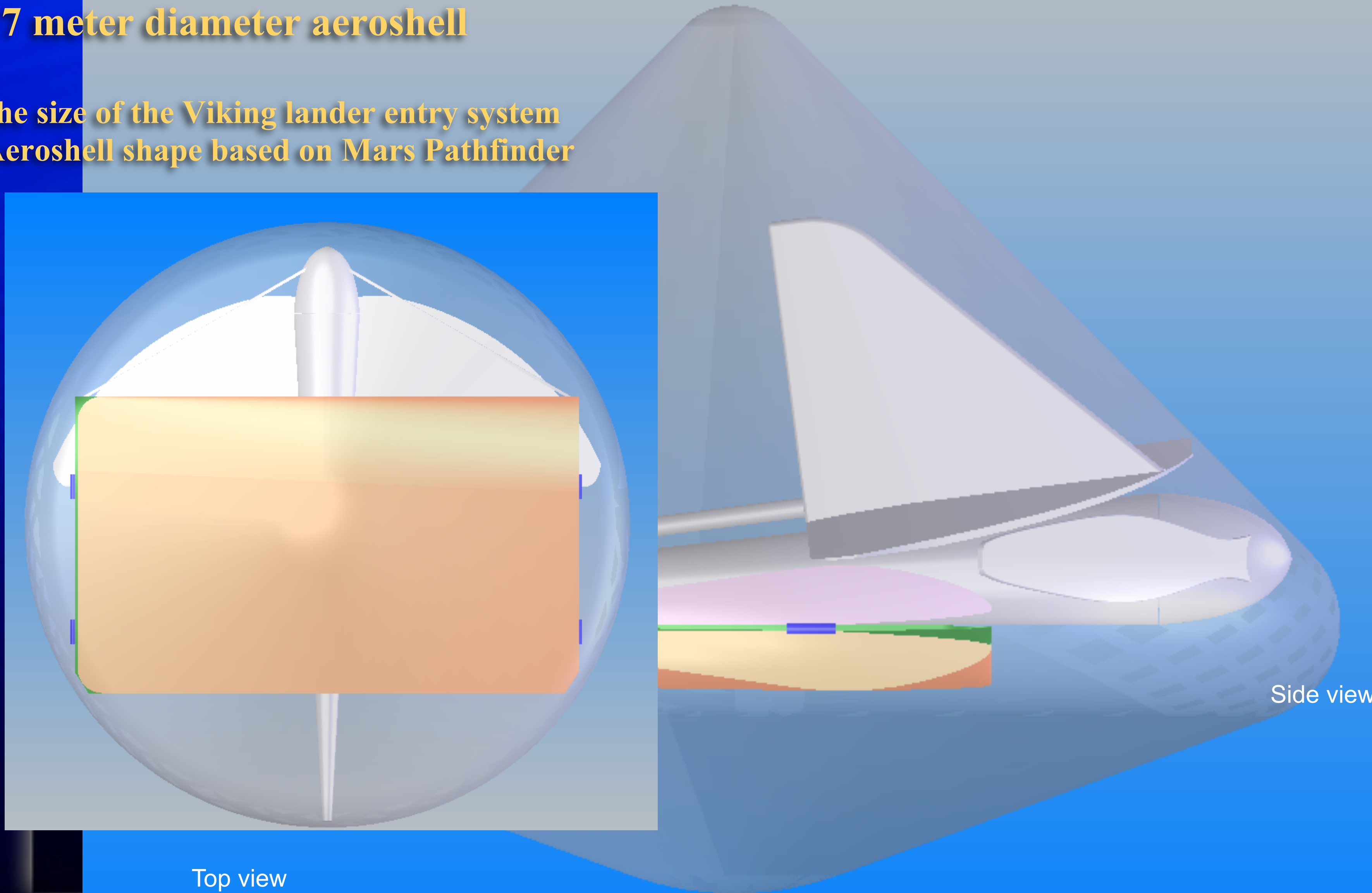
•http://www.lpi.usra.edu/vexag/may2008/presentations/19Landis.mov


Venus
airplane:
plan view

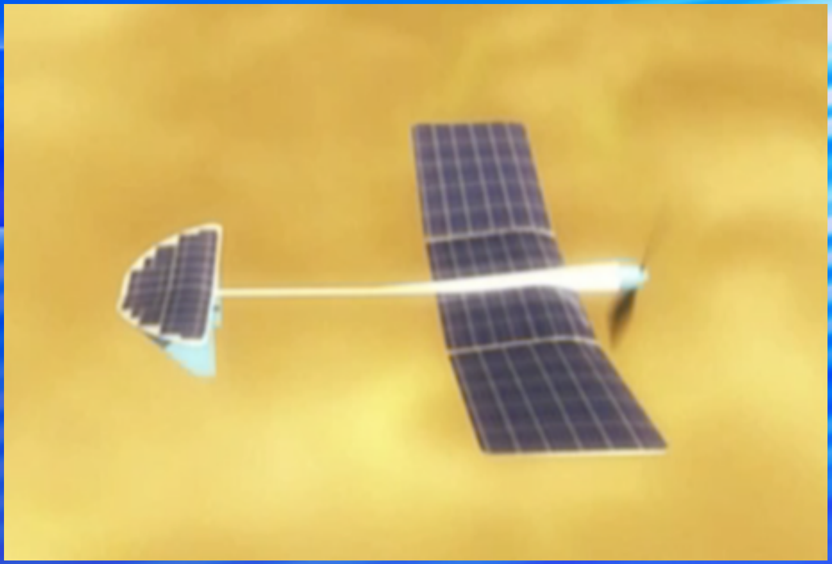
Aircraft folded into aeroshell

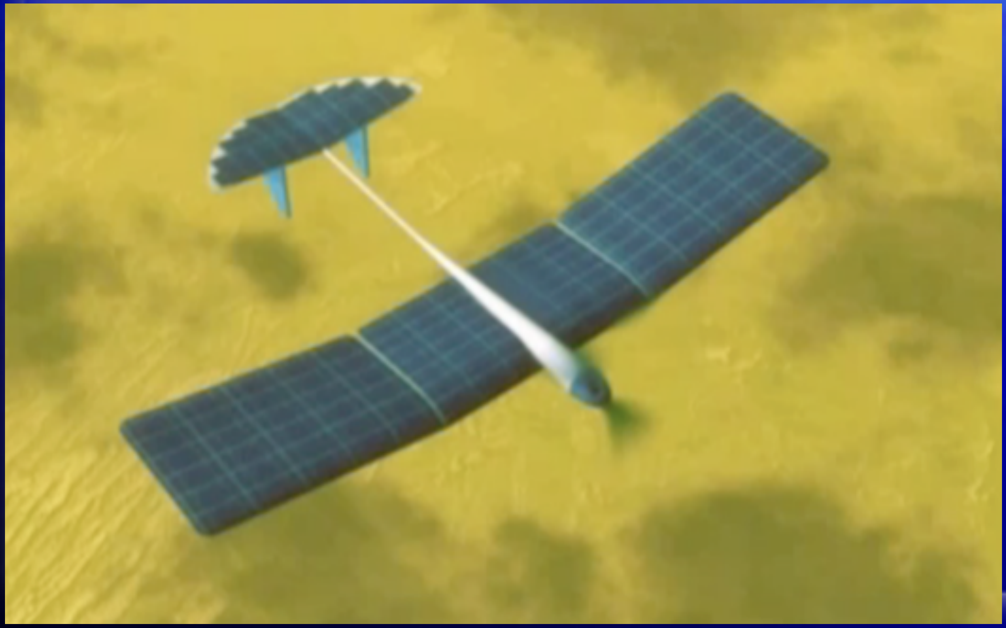
3.7 meter diameter aeroshell

-the size of the Viking lander entry system
-Aeroshell shape based on Mars Pathfinder



RASC Venus airplane Visualization



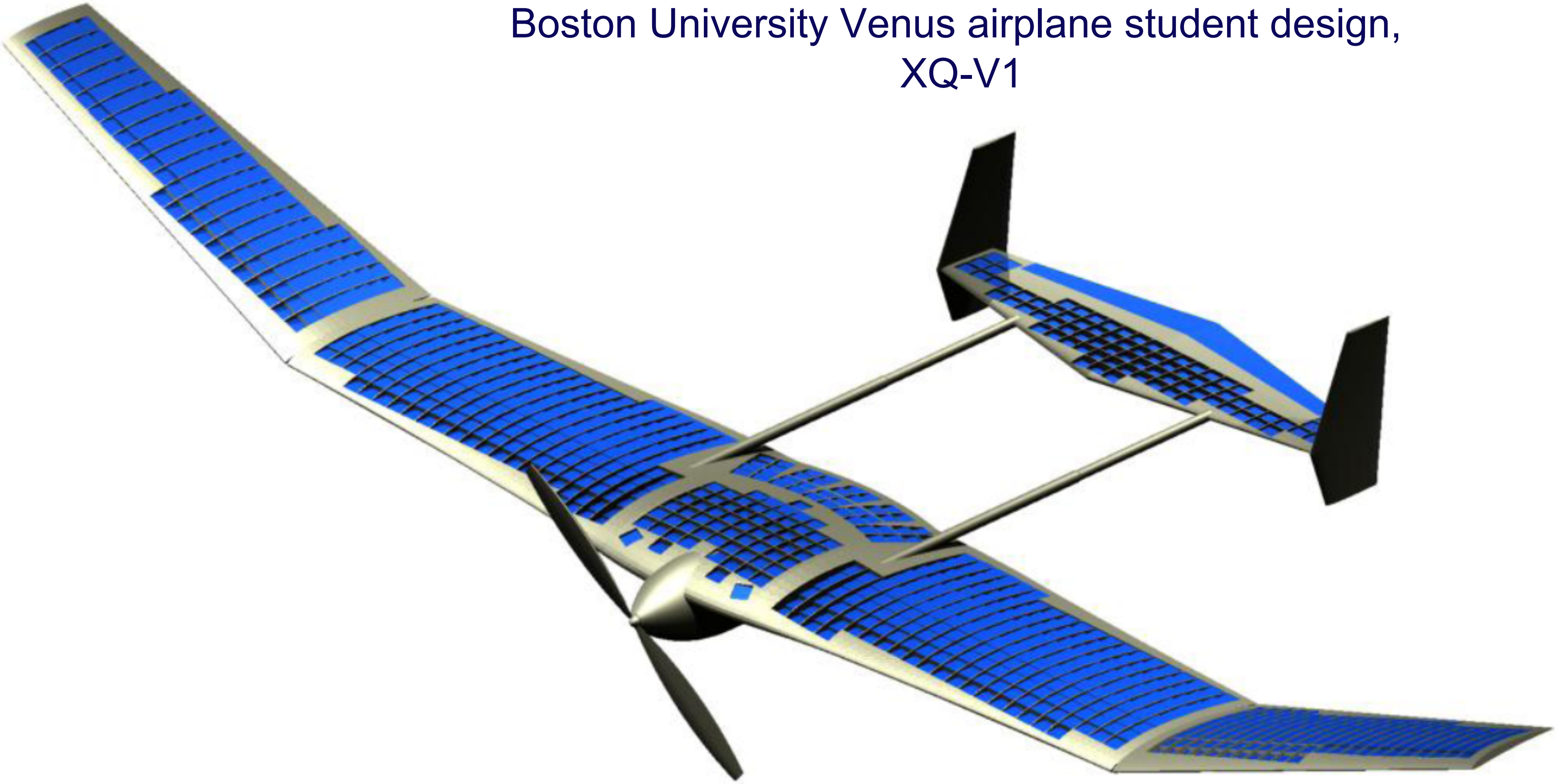


Venus Airplane entry mass

VENUS AIRPLANE MASS SUMMARY			
System Description	**Mass Fraction**	**Mass (kg)**	Source
Airplane	20%	**103**	
Heatsheild Structure	**7%**	36.05	Pioneer
Heatsheild TPS	**13%**	66.95	Pioneer
Backshell Structure (Gussets, Separation ftgs, Paint, Vent, etc)	**12%**	61.80	Pioneer
Backshell TPS	**8%**	41.20	Pioneer
Parachute System	**10%**	51.50	Pioneer
Airplane Deployment Mechanism (Separation from Backshell)	**15%**	77.25	Mars Airplane
Misc (COMM, Power, Ballast, etc)	**15%**	77.25	Mars Airplane
Total Entry Mass	100%	515	
Contingency Mass	30%	155	
Total With Contingency		**670**	

NOTE: Mass Fractions Based off Mars Airplane Data Venus Pioneer

Boston University Venus airplane student design,
XQ-V1

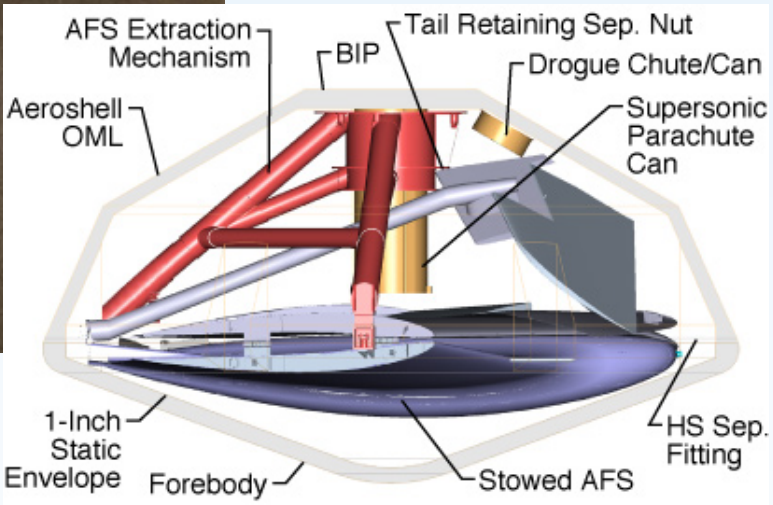


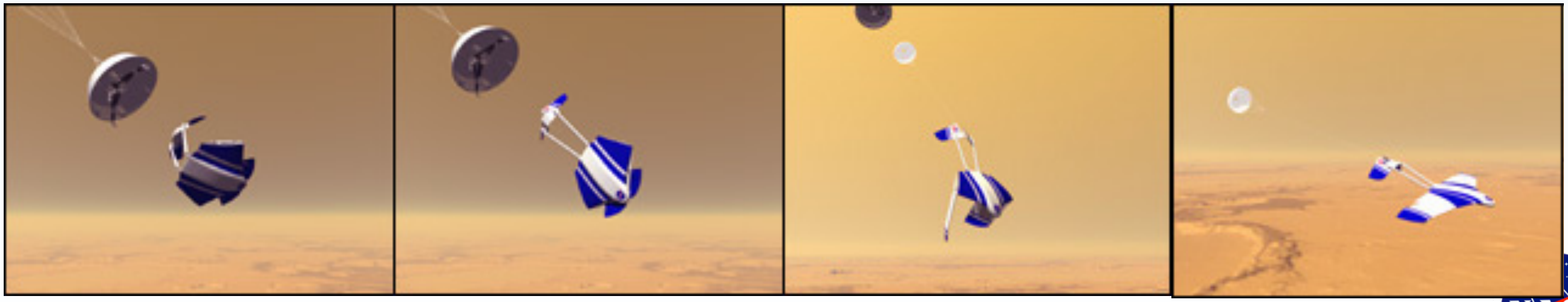
•2008. Image courtesy of Greg Thanavaro, Boston University Dept. of Aerospace Engineering

Mars airplane

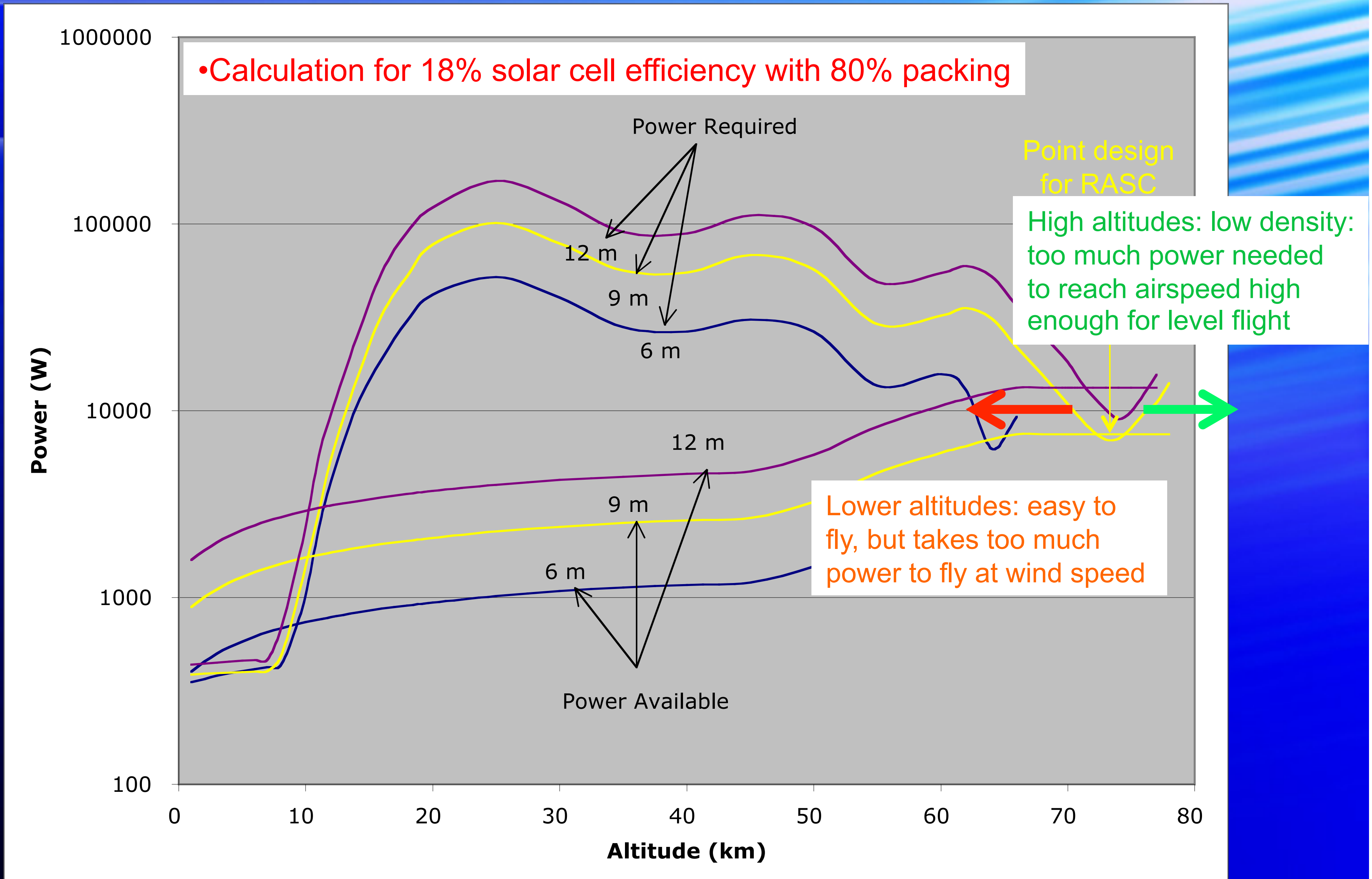
ARES Mars airplane demonstration models

- 6.25 m span
- Aspect ratio 5.6
- 101 kg including margin





Power Required to fly at wind speed versus solar availability



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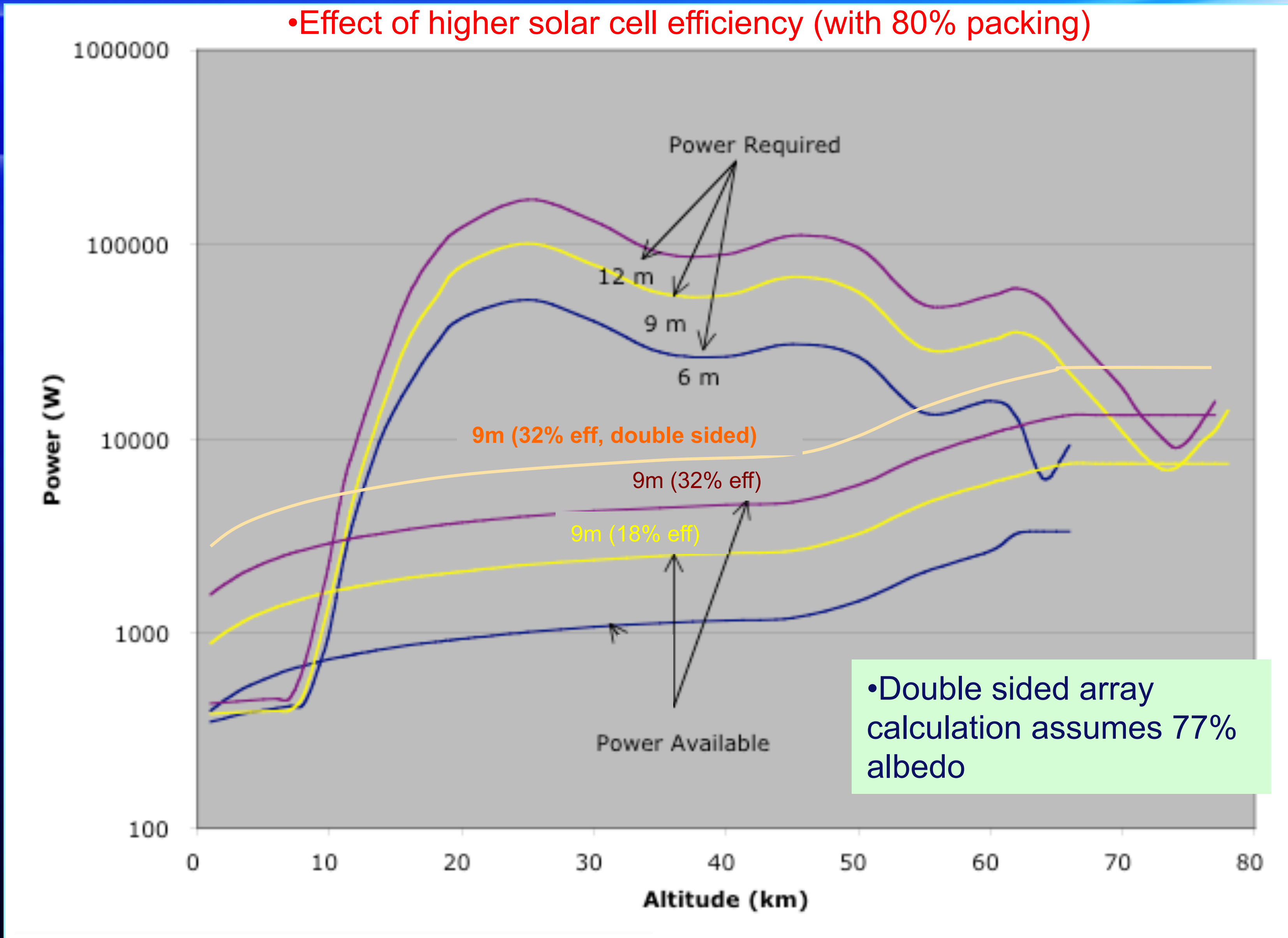
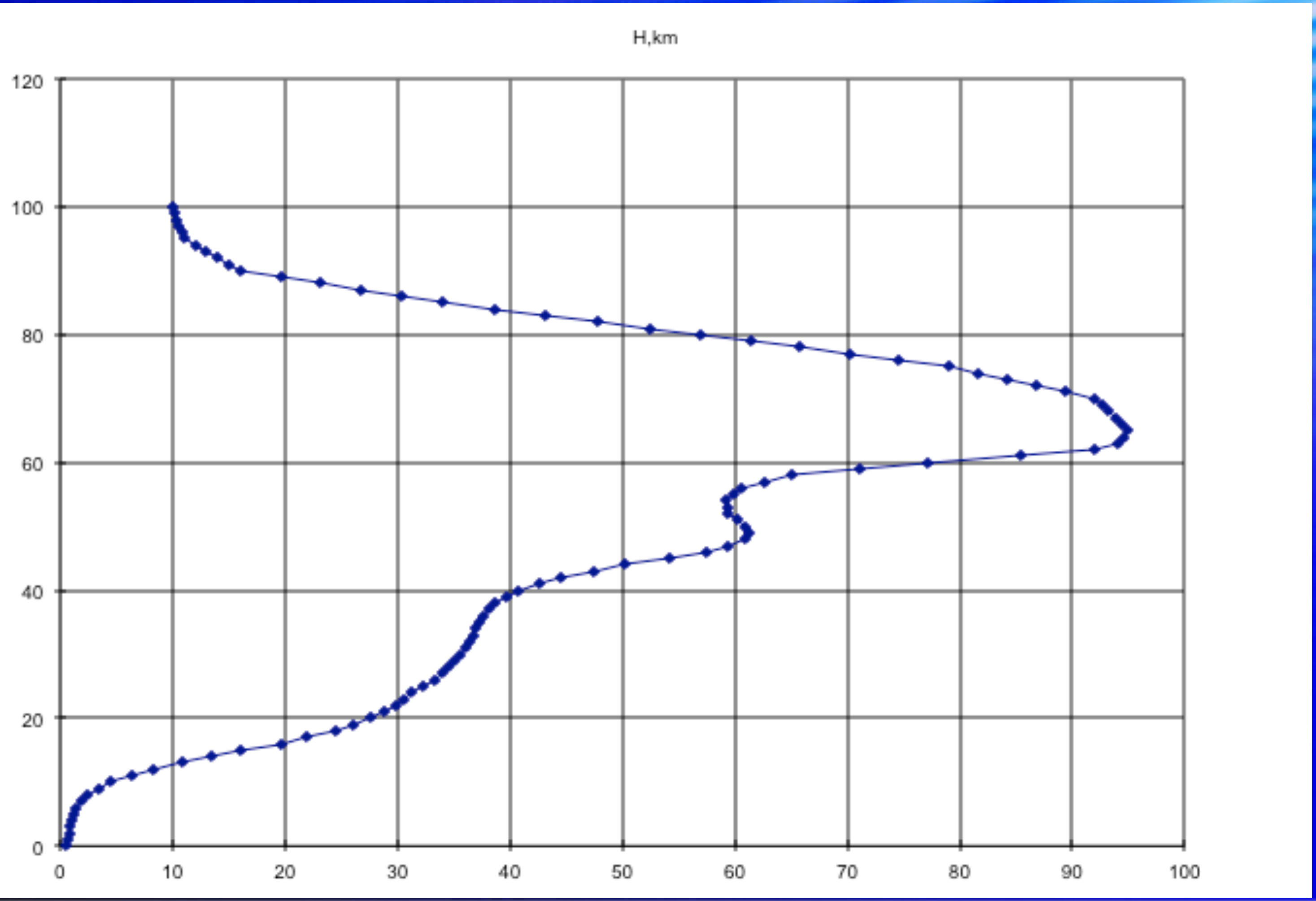


Wind model used



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- A. Colozza and G. Landis, "Evaluation of Long-Duration Flight on Venus," paper AIAA 2005-7156, AIAA Infotech Aerospace Conference 2005, Arlington VA, September 26-29, 2005. *NASA Technical Memorandum* TM-2006-214452 (2006).

(simplified) Aerodynamics of flight on Venus

For flying at a given velocity:

- $C_L A = 2mg/\rho V^2$

•To fly faster, we can *either* decrease the wing area at constant C_L, or else decrease C_L, and hence fly at a less-optimum lift conditions

- Power = drag force times velocity
  - the simplifying assumption that drag is proportional to lift via L/D (lift to drag) ratio becomes poor for flight far from optimum C_L
  - Optimally, you would want to stay at optimum C_L and vary wing area
  - But the constant L/D approximation ignores parasitic drag, which becomes more important as wing area decreases
- $P = mgV/(L/D)$
  - If you could optimize everything and ignore parasitic drag, the power required to fly is independent of density and proportional only to velocity
- But, for a solar aircraft, P is proportional to intensity time wing area A
- Iterative design process needed
- Too simplified: Parasitic drag can't be ignored!